X-621-70-14

PREPRINT

NASA TM X- 63836

A POLAR PEAK OF ELECTRON CONCENTRATION AT 1000 KILOMETERS ALTITUDE

L. H. BRACE
H. G. MAYR
K. K. MAHAJAN

JANUARY 1970

GSFC — GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

X-621-70-14

PREPRINT

A POLAR PEAK OF ELECTRON CONCENTRATION AT 1000 KILOMETERS ALTITUDE

L. H. Brace

H. G. Mayr

K. K. Mahajan*

January 1970

GODDARD SPACE FLIGHT CENTER

Greenbelt, Maryland

*National Academy of Science–National Research Council Associate.

PRECEDING PAGE BLANK NOT FILMED.

A POLAR PEAK OF ELECTRON CONCENTRATION AT 1000 KILOMETERS ALTITUDE

L. H. Brace, H. G. Mayr and K. K. Mahajan

ABSTRACT

Satellite probe measurements from a circular, polar orbit at 1000 kilometers altitude have revealed a broad enhancement of ionization within the polar cap. The latitude of the maximum concentration closely follows the seasonal movement of the solar terminator across the polar cap. The peak is bounded on its nightside by a solar zenith angle of about 110° and on its dayside by a broad midlatitude trough near 60° geomagnetic latitude. Thus one boundary of the peak, and the location of the maximum, is strongly influenced by solar zenith angle while the other boundary is geomagnetically fixed. Although the ionization and heating observed in the peak clearly arises from solar radiation, the most intriguing question is why a peak should be formed at all since this cannot be produced by zenith angle variations alone. The answer appears to lie in the mechanisms which produce the midlatitude trough on the dayside. To explain the trough we invoke the effects of neutral atmospheric winds flowing poleward on the dayside of the earth in response to solar heating. The observations are shown to agree quantitatively with solutions of the energy and particle equations of the plasma when a neutral wind field derived from a Jacchia model atmosphere is introduced and suitable allowance is made for an upward proton flux at high latitudes.

We also conclude that the polar peak discussed here and the one observed by Nishida and interpreted as a neutral point phenomenon may actually be the same feature. Nishida's study employed only data acquired near equinox, thus he could not resolve the seasonal movement we describe here.

CONTENTS

A POLAR PEAK OF ELECTRON CONCENTRATION

AT 1000 KILOMETERS ALTITUDE

INTRODUCTION

The high latitude topside ionosphere has been the subject of many satellite investigations (Thomas and Sader, 1964) (Muldrew, 1965) (Thomas et al., 1966) (Nishida, 1967) (Sato and Colin, 1969) (Jelly and Petrie, 1969) (Chan and Colin, 1969) (Brace, 1969) (Miller and Brace, 1969). This region exhibits a great deal of complex behavior in the form of peaks and troughs with considerable spatial and temporal variation. However several large-scale features of the high latitude ionosphere are found rather consistently, and these represent the background behavior of that region. The subject of this paper is a discussion of one of these permanent features called the polar peak. This feature was described by Nishida and attributed to solar plasma penetrating the ionosphere at the magnetospheric neutral point near 80° geomagnetic latitude. Our electrostatic probe measurement from Explorer 22 do not support this explanation for the polar peak.

THE EXPERIMENT

The Explorer 22 satellite was launched on October 10, 1964 into a nearly circular orbit (1000 ± 100 km) having an 80° inclination. The cylindrical probe was placed aboard to provide measurements of the local electron concentration (N_e) and temperature (T_e). Brace and Reddy (1965) and Brace et al., (1967) have described the method. The current sensitivities and voltage sweep rate employed

in this satellite permitted N_e to be measured in the range $1 \times 10^2 - 5 \times 10^4$ cm^{-3} and T_e in the range 500°–20,000°K. The relative accuracies of the data employed in this study are believed to be better than 10%. Comparisons with other probe and sounder methods (Donley et al., 1969) suggests that the absolute accuracy is better than 20% in N_e and better than 10% for T_e.

EXPERIMENTAL DATA

In the Explorer 22 probe experiment, the normal mode of operation permits measurements to be made at 3 minute intervals along the orbit, an interval that permits latitudinal resolution of about 10°. The broad network of STADAN telemetry stations at high northern latitudes provides nearly complete coverage of the polar cap. For this study data were employed from passes over England, Newfoundland, North Central U. S., and Alaska. All of these stations can receive data to the highest latitude reached by the satellite (80°).

Pole-to-Pole Plots

To aid in surveying the T_e and N_e measurements, pole-to-pole computer plots of each entire week of data are prepared routinely. The values are usually plotted against geomagnetic, invariant or dip latitude because magnetic coordinates provide a high degree of ordering of the data from a wide range of longitudes. Figure 1a is a typical weekly plot of N_e versus geomagnetic latitude. The data are from the period May 12-19, 1965.

In routine viewing of many of the weekly plots it was readily apparent that some features of the polar ionosphere were not as well ordered as were features

at lower latitudes. In particular a broad peak of N_e within the polar cap was poorly resolved in geomagnetic latitude even though the concentrations in the peak were often as high as that found at low latitudes. A second feature, that we refer to here as the "midlatitude trough," always marks the dayside or equatorward boundary of the polar peak. Unlike the peak, this trough is well ordered on a geomagnetic latitude plot and is consistently found to be centered near 60° geomagnetic latitude.

The geomagnetic latitude of the peak itself was found to differ by as much as 25° between passes taken on the same day but at different longitudes, a fact that demonstrates the poor correlation of the peak with magnetically controlled processes.

To investigate the possibility that the peak was produced by solar ultraviolet radiation, the data in Figure 1a was replotted versus geographic latitude as shown in Figure 1b. The peak is notably better resolved in this plot, especially the location of the maximum and the steep slope which forms its nightside boundary. This shows that the peak is encountered by the satellite at the same geographic latitude regardless of the earth meridian that happens to be beneath the orbit at the time of the pass. In each case, as will be shown, the first trace of enhancement began at a solar zenith angle of between 105 and 110°, with the maximum concentration occurring near a zenith angle of 85°.

Seasonal Behavior of the Peak

Previous examination of Explorer 22 data from different seasons (Brace, 1969) has shown that a deep trough of N_e over the pole in winter gives way to

generally high values of N_e in summer. Hagg (1968) reported similar results from Alouette-II.

To examine this seasonal variation of the polar peak in detail, we selected one-week periods in winter, spring and summer and repeated this for two consecutive years. In each of these periods, the satellites orbital plane was within 3 hours of the noon-midnight plane. Thus the satellite encountered the solar terminator high in the polar region and crossed it nearly perpendicularly. This permits any solar zenith angle effects in the ionosphere to be encountered abruptly. Figures 2 and 3 show the seasonal movement of the polar peak in these two years, 1965 and 1966.

The initial rise in N_e occurs near the solar zenith angle of 105° (small arrow) in all six periods. The geographic latitude at this point varies widely with season. In summer, the 105° point occurs well into the "nightside" of the polar cap, and conversely it moves slightly into the "dayside" of the polar cap in winter.

The weeks selected for this study were not unique. A broad survey of the data plots from weeks adjacent to those shown here reveals the polar peak at its expected location. It must be realized, however, that precession of the orbit limits our seasonal resolution of solar terminator effects within the polar cap. For example, in those periods when the orbital plane tends to parallel the terminator, the satellite may not cross the terminator at all within the polar cap. (When the terminator is crossed at lower latitudes we observe sunrise or

sunset effects in T_e and N_e that are similar in some respects to the polar peak enhancements but are complicated by heat and particle exchange with the overlying protonosphere.)

The Midlatitude Trough

As noted earlier, a key feature inherent in all of the observations of the polar peak is the existence of the midlatitude trough of N_e on its dayside. Indeed it is this trough that makes the polar enhancement appear as a peak. From geomagnetic plots such as shown in Figure 1a, one finds that the location of the trough does not follow the seasonal movement of the peak, but remains near 60° geomagnetic latitude. This magnetic influence is also evident in the higher degree of ordering of the trough within the data from each week when plotted versus geomagnetic latitude.

Because of the seasonal movement of the peak, its location relative to the midlatitude trough varies greatly. In polar summer, when the peak is furthest from the trough, they are separated by about 40 to 60° depending upon the longitude. Conversely, in polar winter, the peak moves into the trough region and its amplitude is greatly depressed. The peak may be entirely absent at European longitudes where the trough occurs at the highest geographic latitudes. In effect the mechanism that forms the trough appears to entirely suppress the peak.

From the behavior described above it is clear that the key to the polar peak behavior lies in the processes that form the midlatitude trough, a topic which we will return to later.

The Electron Temperature

If the ionization in the polar peak is produced by solar ultraviolet radiation, as seems clear from the solar zenith angle dependence just described, we can also expect increases in T_e near the terminator. Figure 4 compares the T_e and N_e behavior at this boundary during a 3-day period in the winter of 1965. The measurements from 6 Alaska passes are plotted versus solar zenith angle. Typical values of N_e within the winter polar trough at the right are about 500 electrons/cc, concentrations too low to permit precise T_e measurements with the current sensitivity employed on Explorer 22. On most passes the initial rise in N_e is found between 105° and 110° zenith angle. T_e is already rising by the time it becomes measurable. On one pass in this series the zenith angle effect appears to be masked by a local enhancement of T_e and N_e. These occur sporadically, and perhaps represent particle precipitation events (Donley, 1967). In any case, it is clear from Figure 4 that the large gradient in N_e across the terminator is accompanied by corresponding changes in T_e. It is significant that T_e and N_e do not exhibit a similar correlation on the dayside of the peak where T_e continues to rise throughout the midlatitude trough of N_e.

DISCUSSION

Figure 5 is a sketch of the relationship between the polar peak, the midlatitude trough and the solar terminator for a day in northern summer. We have shown no peak in the southern polar region (winter pole) assuming that its behavior is similar to that of the northern pole. The limited telemetry coverage

of that region permits us to observe only portions of the southern polar peak that are equatorward of 70° south latitude. The geomagnetic field is represented by dashed lines for later discussion.

The commencement of the N_e enhancement at solar zenith angles of about 105° is consistent with the theoretical work of Thomas (1966), although he also predicts increases in N_e at lower altitudes that are not observed. Brinton et al. (1969a) reported sunrise and sunset effects beginning at similar zenith angles from Explorer 32 measurements at lower latitudes. Similarly the seasonal movement of the peak as it follows the terminator across the polar cap leaves little reason to doubt that solar illumination is intimately involved in the formation of the polar peak.

It is equally clear that the trough in N_e on the dayside of the peak must be caused by other processes, since the zenith angle continues to decrease through the trough region. The remainder of this paper deals with a theoretical investigation of the processes that control the midlatitude F-region and ends with a model which reproduces the major features of the trough and the peak.

Qualitative Discussion

When initially considering the origin of the midlatitude trough it is tempting to see if variations in temperature and composition could account for it. These parameters exert a strong control over the plasma scale height, H. In diffusive equilibrium H is given by

$$H = \frac{k\left(T_e + T_i\right)}{2m_i\, g} \quad . \tag{1}$$

The mean ion mass, m_i, approaches 16 throughout the entire upper F-region where the peak is found (below 1000 km and above 60° geomagnetic latitude). T_e exhibits a maximum in the trough region and therefore varies in the wrong sense to produce a trough of N_e. Thus if O^+ were in diffusive equilibrium in the trough region, there would not be a trough unless it also existed in the lower F-region where ion production and loss control N_e. Nishida's (1967) observations show little evidence of the polar peak or the trough at the altitude of the F_2-max. In addition, analysis of Alouette-I sounder data from the periods of this study also shows little trace of the peak at that altitude. Thus we conclude that the trough results from some dynamic process in the atmosphere that prevents the upper F-region at midlatitude from approaching diffusive equilibrium. This implies the existence of a process that produces a downward force upon the ions that in turn reduces the electron scale heights and concentrations throughout the upper F-region. The observations suggest that this force is greatest at midlatitudes and exerts a strong geomagnetic control.

Kohl and King (1967) have demonstrated that the thermally driven global wind system can have important affects upon the global morphology of the ionosphere. Volland and Mayr, (1968) have developed a model for such a wind system based on Jacchia's model of the neutral atmosphere. Brinton et al. (1969b) have invoked this wind model to explain the strong hemispherical asymmetry they observed in the O^+ - H^+ transition altitude at American longitudes. Similarly Brace et al. (1969) showed that daytime rocket borne measurements of T_e and

N_e within the trough region could be explained by similar wind velocities. Thus it appears that the midlatitude trough can be understood qualitatively in terms of winds in the neutral atmosphere.

Neutral wind models show that the wind flows poleward on the sunlit side of the Earth. Since the ions resist movement perpendicular to the geomagnetic field on which they are effectively frozen, collisions between the ions and neutrals induce a drag force that has a component down the field line. This produces both a reduction of the plasma scale height and a lowering of the altitude and concentration at the F_2-max. The combined effect is to reduce the electron and ion concentration at all altitudes above the F_2-max.

This process is an especially appealing mechanism for explaining both the midlatitude trough and the polar peak because it is most effective at midlatitudes where the dip of the field provides a maximum vertical component of ion-neutral drag as can be seen in Figure 5. At the higher latitudes where the peak is found, the field is nearly vertical and the largely horizontal winds have only small components along the field lines. This dip angle dependence is consistent with the remaining observational point, namely, the geomagnetic control of the trough location.

<u>The Effect of Winds on the Nightside</u>

Before discussing a more quantitative treatment of the midlatitude trough problem, it is interesting to consider the effect of the wind upon the nightside midlatitude ionosphere. Since the winds flow equatorward, one expects an

uplifting of the F-region, reduced recombination, and generally enhanced plasma concentrations at midlatitudes (Kohl and King, 1967). Increases in scale height further enhance the concentrations at higher altitudes. The nightside data in Figures 1a and 1b tend to exhibit this kind of behavior between 20° and 50° latitude where the electron concentration is higher than elsewhere on the nightside. Indeed, at 40° the nighttime values of N_e at 1000 kilometers actually exceeds the daytime values, at least at solar minimum (Brace et al., 1968) (King et al., 1968).

It is puzzling that this nightside enhancement of N_e is limited to lower midlatitudes and is not evident at 60°. Instead there is a rather narrow trough at 60°, called the "main trough" by Muldrew (1965), whose origin is not fully understood. Apparently a very effective depletion process is operating at that location, a process that reduces the electron concentration throughout the F-region (Thomas and Sader, 1964) (Sharp 1966). The wind-induced drag forces have only a minor effect by comparison.

Analysis of the Trough and Peak Formation

Following the method of Mayr et al. (1967) we have calculated the latitudinal variation of N_e as a function of latitude, first for an ionosphere in diffusive equilibrium and then introducing processes which permit departures from diffusive equilibrium. The calculations represent a simultaneous solution of the particle and energy equations for the plasma (Mayr et al. 1969). They include the effect of the ion and electron temperatures and their gradients. Force terms

are included in the O^+ and H^+ momentum equations to account for ion-neutral drag effects of the neutral wind and ion-ion drag effects of proton fluxes into and out of the protonosphere (Brace et al. 1969). The photoelectron flux (non-local heating) and the solar ultraviolet flux (local electron heating) were also adopted following Brace et al. (1969).

To avoid arbitrary lower boundary conditions on N_e, T_e and T_i, the calculation was begun at 170 kilometers where local production and loss of O^+ established N_e and local heating and cooling established T_e and T_i. T_n, the gas temperature, was derived from the same Jacchia model as employed for the wind field (T_∞ = 830°). The profile of T_e measured at 1000 kilometers at equinox was employed as a second boundary condition on the temperature calculations. The effects of atmospheric attenuation of solar ultraviolet at low zenith angles was included assuming H_e 304 to be the primary F-region ionization source. For this purpose the season was assumed to be equinox when a zenith angle of 90° occurs at the pole. The geomagnetic and geographic poles were assumed to lie on a common meridian. The calculations were performed for the field lines 30°, 45°, 60°, 80° and 90° geomagnetic (and geographic) latitude, and smooth latitude profiles were derived by fitting those points.

The Equilibrium Case

Neglecting dynamic processes in the atmosphere, one expects a general decrease in N_e toward higher latitudes where solar zenith angle effects become important. To demonstrate this, Figure 6 shows calculated latitude profiles at

several altitudes for an ionosphere in equilibrium. No trough is present at mid-latitudes and the concentrations are about a factor of 4 greater than are observed. Clearly the observations are not consistent with the equilibrium calculations.

The Effect of Winds

To closer match the observations; that is, to produce a trough in N_e at mid-latitudes, we introduced the poleward neutral wind field derived by Volland and Mayr (1968). Table I shows the wind speeds as a function of latitude. The effect of this wind on the latitudinal profiles is shown in light solid lines in Figure 7. At 200 kilometers and at the F_2-peak the wind has little or no effect, as this region is dominated by local production and loss of O^+. However, above the F_2-peak a trough develops whose relative depth is consistent with the observations at 1000 kilometers. But the location of the calculated trough is about 10° too far south.

Proton Fluxes

In earlier studies of this type Mayr et al. (1967), Mayr et al. (1969) found evidence for proton fluxes flowing upward into the protonosphere at latitudes above 50°. Banks and Holzer (1969) also predict such fluxes associated with the polar wind. These proton fluxes deplete the H^+ population and thus decrease the plasma scale heights in the $O^+ - H^+$ transition region. By introducing fluxes that increase with latitude it is possible to shift the position of the trough to 60° to match the observations. Figure 7 shows the resulting solution in heavy

solid lines. The proton flux required is shown in Table I. These fluxes are everywhere less than the critical flux that can be maintained by production of protons through charge exchange when currently accepted hydrogen concentrations are employed (Meier, 1969).

Other features of the theoretical trough, and the resulting peak at higher latitudes, are also similar to the observations. The peak itself is located at a zenith angle of about 80°, in acceptable agreement with the observed peak near 85°. Our calculations are not carried to large enough zenith angles to evaluate the nightside of the peak, but the observations exhibit acceptable agreement with the theoretical work of Thomas (1966) for large zenith angles. The growth in the amplitude of the peak with altitude is consistent with the observations of Nishida (1967).

The Polar Peak of Nishida

As noted earlier Nishida (1967) reported observations of a polar peak which he found in Alouette-I measurements taken near equinox 1963 and 1964. Nishida (1967) and Thomas et al. (1966) attributed this enhancement to the precipitation of solar wind particles entering the magnetosphere at the neutral point near 80° geomagnetic latitude on the dayside of the Earth. It may be less than coincidental that the polar peak we have discussed here is also found near 80° at equinox. Furthermore we observe no other stable peak at this location. Although the two sets of observations are not from the same years, it seems likely

that these two polar peaks are the same phenomenon. The seasonal movement of the peak may not have been readily resolvable in Nishida's data since it was taken near equinox.

It should be reemphasized that other peaks are often observed in the polar ionosphere, and these may exhibit a high degree of magnetic ordering (Sato and Colin, 1969) (Colin et al., 1969) (Miller and Brace, 1969). However, these features are more sporadic in occurrence and often more localized in extent and should not be confused with the large scale phenomenon we have discussed here that is a consistent feature of the polar ionosphere.

SUMMARY

In this study we have shown that a peak of N_e exists in the upper F-region of the polar ionosphere, an enhancement that follows the seasonal changes in solar zenith angle. The peak is bounded on its nightside by zenith angles of 105 to 110° and is bounded on its dayside by a midlatitude trough at 60° geomagnetic latitude. Thus the width of the peak varies with longitude. In winter the peak moves into the midlatitude trough region and is depressed in amplitude.

The midlatitude trough and its associated polar peak can be reproduced theoretically by invoking ion-neutral drag forces produced by poleward winds flowing in the neutral atmosphere and upward proton fluxes that increase with latitude. The poleward winds on the dayside of the Earth produce reductions in N_e at midlatitudes where the dip of the field permits the ion-neutral

drag to be most effective. Conversely, equatorward winds on the nightside of the Earth tend to produce midlatitude enhancements of N_e, a feature that is also observed.

We suggest that the polar peak reported by Nishida and attributed to particle heating at the magnetospheric neutral point may simply represent the equinoctial location of the polar peak discussed here.

ACKNOWLEDGMENTS

The authors are grateful to Joseph Johnson for his work in reducing the data and Robert Theis for developing the computer plotting programs employed for displaying the data.

REFERENCES

Banks, P. M., T. E. Holzer, "High Latitude Transport: The Polar Wind," J. Geophys. Res., 74, 6317, 1969.

Brace, L. H., "The Global Structure of Ionosphere Temperature," presented at 12th International COSPAR meeting Prague, May 1969 (to be published in Space Res. 12).

Brace, L. H., B. M. Reddy, "Early Electrostatic Probe Measurements from Explorer 22," J. Geophys. Res., 70, 5783, 1965.

Brace, L. H., H. G. Mayr, B. M. Reddy, "The Early Effects of Increasing Solar Activity upon the Temperature and Density of the 1000 Kilometer Ionosphere," J. Geophys. Res. 73, 1607, 1968.

Brace, L. H., H. G. Mayr, and J. A. Findlay, "Electron Measurements Bearing on the Energy and Particle Balance of the Upper F-Region," J. Geophys. Res., 74, 2952-61, 1969.

Brace, L. H., B. M. Reddy and H. G. Mayr, "Global Behavior of the Ionosphere at 1000 Kilometer Altitude," J. Geophys. Res., 72, 265, 1967.

Brinton, H. C., H. G. Mayr, R. A. Pickett and H. A. Taylor, Jr., "The Effect of Atmospheric Winds on the O^+ - H^+ Transistion Level," presented at 12th International COSPAR Meeting, Prague, 1969b (to be published Space Res. 12).

Brinton, H. C., R. A. Pickett and H. A. Taylor, Jr., "Diurnal and Seasonal Variations of Atmospheric Ion Composition; Correlation with Solar Zenith Angle," J. Geophys. Res., 74, 4064-73, 1969a.

Chan, K. L., Lawrence Colin, "Global Electron Density Distributions from Topside Soundings," Proc. I.E.E.E., 57, 6, 990, 1969.

Donley, J. L., "Observations of the polar ionosphere in the altitude range 2000 to 3000 km by means of satellite-borne electron traps," Space Research VIII, p. 382-389, North-Holland Publishing Co., Amsterdam, 1967.

Donley, J. L., L. H. Brace, J. A. Findlay, J. H. Hoffman, and G. L. Wrenn, "Comparison of Results of Explorer 31 Direct Measurement Probes," Proc. IEEE, 57, 1078, 1969.

Hagg, E. L., "Electron densities of 8-100/cc deduced from Alouette-II high latitude ionograms," Canadian J. Phys., 45, 27, 1967.

Jelly, O. H., L. E. Petrie, "The High Latitude Ionosphere," Proc. IEEE, 57, 6, 1005, 1969.

King, J. W., H. G. Rix, and C. Seabrook, "The behavior of the topside ionosphere at middle latitudes at night," Journ. of Atmos. and Terr. Physics, 30, 1605-1613, 1968.

Kohl, H. and J. W. King, "Atmospheric Winds Between 100 and 700 km and Their Effects on the Ionosphere," Journ. Atmos., Terr. Phys., 29, 1045, 1967.

Mayr, H. G., L. H. Brace, G. S. Dunham, "Ion Composition and Temperature in the Topside Ionosphere," J. Geophys. Res., 72, 4391, 1967.

Mayr, H. G., L. H. Brace and W. Crevier, "The Latitudinal Temperature Structure of the Topside Ionosphere," X-621-68-233, Goddard Space Flight Center, Greenbelt, Md., 1968.

Meier, R. R., "Balmer Alpha and Lyman Beta and the Hydrogen Geocorona," J. Geophys. Res., 74, 3561, 1969.

Miller, N. J., and L. H. Brace, "Some Winter Characteristics of the Northern High-latitude Ionosphere," J. Geophys. Res., 74, 5752, 1969.

Muldrew, D. B., "F-layer ionization troughs deduced from Alouette-I data," J. Geophys. Res., 70, 2635, 1965.

Nishida, A., "Average Structure and Storm-time Change of the Polar Topside Ionosphere at Sunspot Minimum," J. Geophys. Res., 72, 6051, 1967.

Sato, T., and L. Colin, "Morphology of Electron Concentration Enhancements at a Height of 1000 Kilometers at Polar Latitudes," J. Geophys. Res., 74, 2193, 1969.

Sharp, G. W., "Midlatitude Trough in the Night Ionosphere," J. Geophys. Res., 71, 1345, 1966.

Thomas, J. O., M. J. Rycroft, L. Colin, and K. L. Chan, "The Topside Ionosphere, 2, Experimental Results from the Alouette-I satellite," Electron Density Profiles in Ionosphere and Exosphere, pp. 322-357, North-Holland Publishing Co., Amsterdam, 1966.

Thomas, J. O. and A. V. Sader, "Electron Density at the Alouette Orbit," J. Geophys. Res., 69, 4561, 1964.

Thomas, L., "The Importance of photoionization in the production of the daytime F-region at high latitudes during winter," Planet. Space Sci., 14, 891, 1966.

Volland, H., and H. G. Mayr, "On the Diurnal Tide Within the Thermosphere," Goddard Space Flight Center Document X-621-68-444, 1968.

Table I

Neutral Winds and Proton Fluxes

Latitude	30°	40°	50°	60°	70°	80°	85°
Horizontal Wind (m/s)	51.6	84.4	11.6	141.4	163.8	180.2	187.8
Wind Component $\parallel$ to Field (m/s)	-33.9	-43.3	-44.4	-39.2	-29.3	-15.9	-8.2
Proton Flux at 1000 km (cm^{-2} sec^{-1})	0	0	1×10^7	2.5×10^7	3.5×10^7	4×10^7	4×10^7

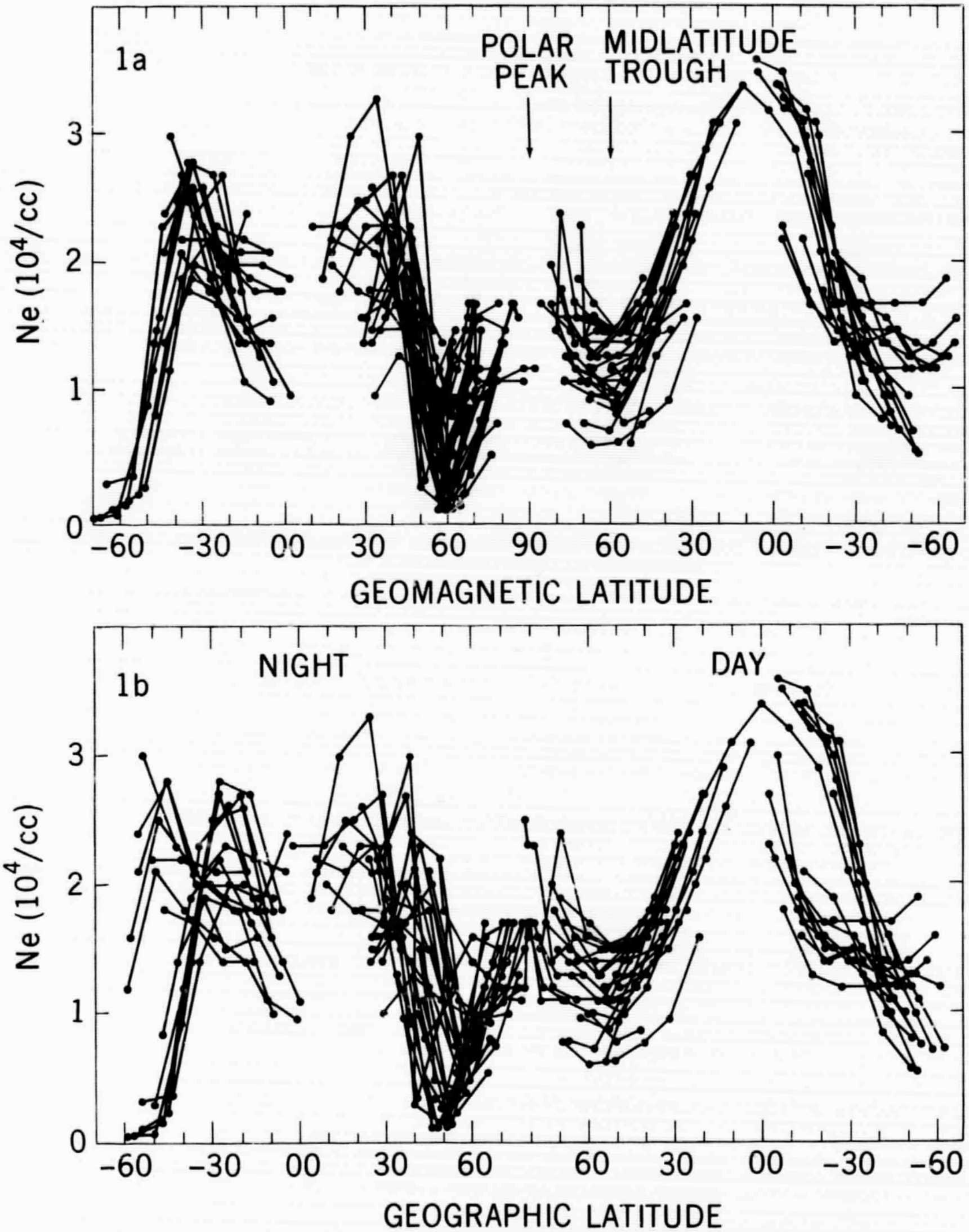

Figure 1a–Pole to Pole plot of N_e measurement from the week of 15-22 May 1966 versus geomagnetic latitude. The satellite was in a circular orbit at 1000 kilometers altitude. Individual measurements from a given pass are connected by straight lines, except when they cross the pole.

Figure 1b–Pole to Pole plot of the same N_e data as in 1a but plotted versus geographic latitude. The peak and its nightside boundary are much better resolved on this scale.

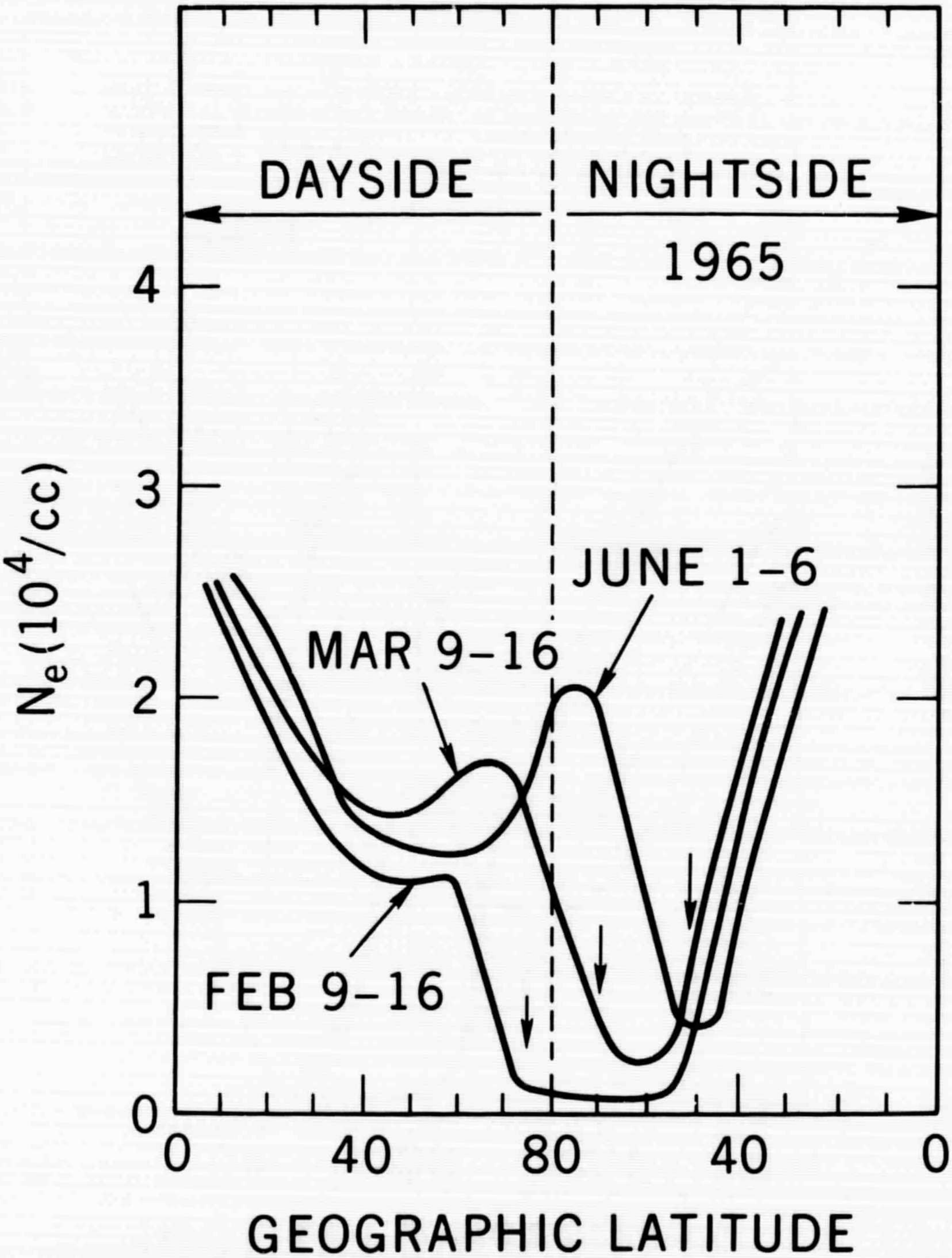

Figure 2-Seasonal behavior of the polar peak in 1965. Each solid line represents an average of data from the week indicated. The arrows mark the point where the solar zenith angle is 105°. In all seasons the initial enhancement occurs at this location.

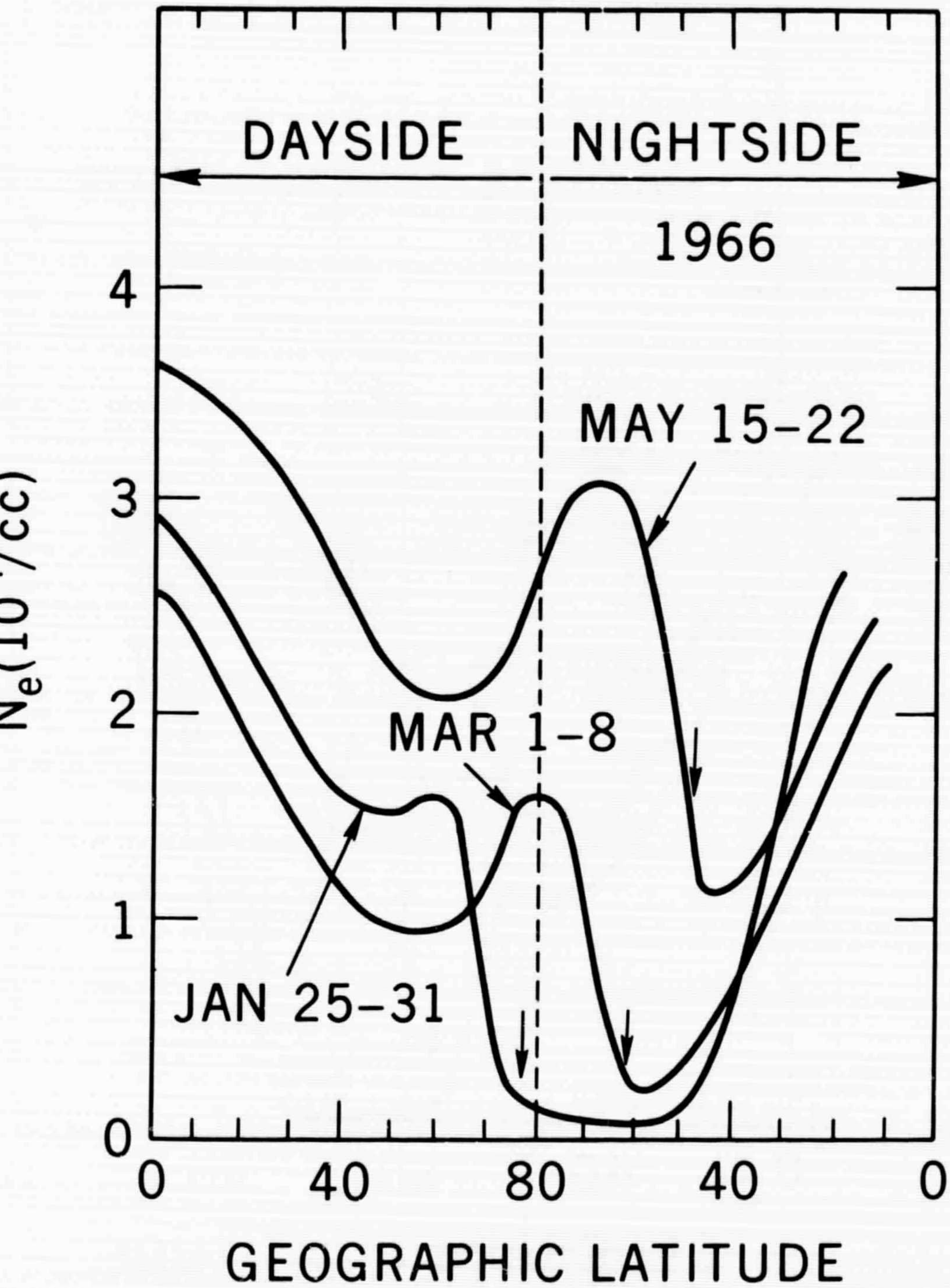

Figure 3–Seasonal behavior of the peak in 1966. As in Figure 2, the arrows are at a zenith angle of 105°

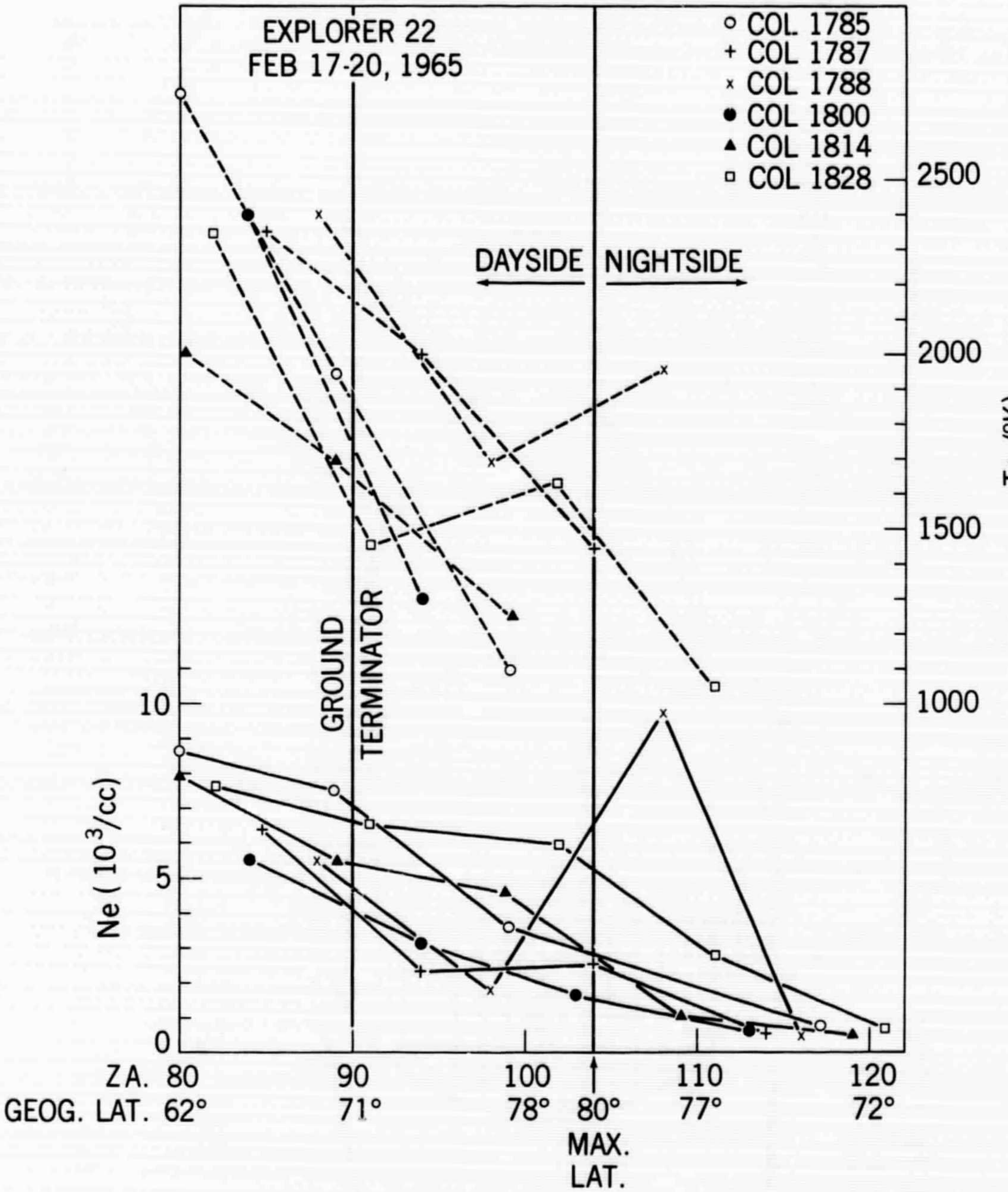

Figure 4-Relationship between T_e and N_e in the nightside boundary of the peak.

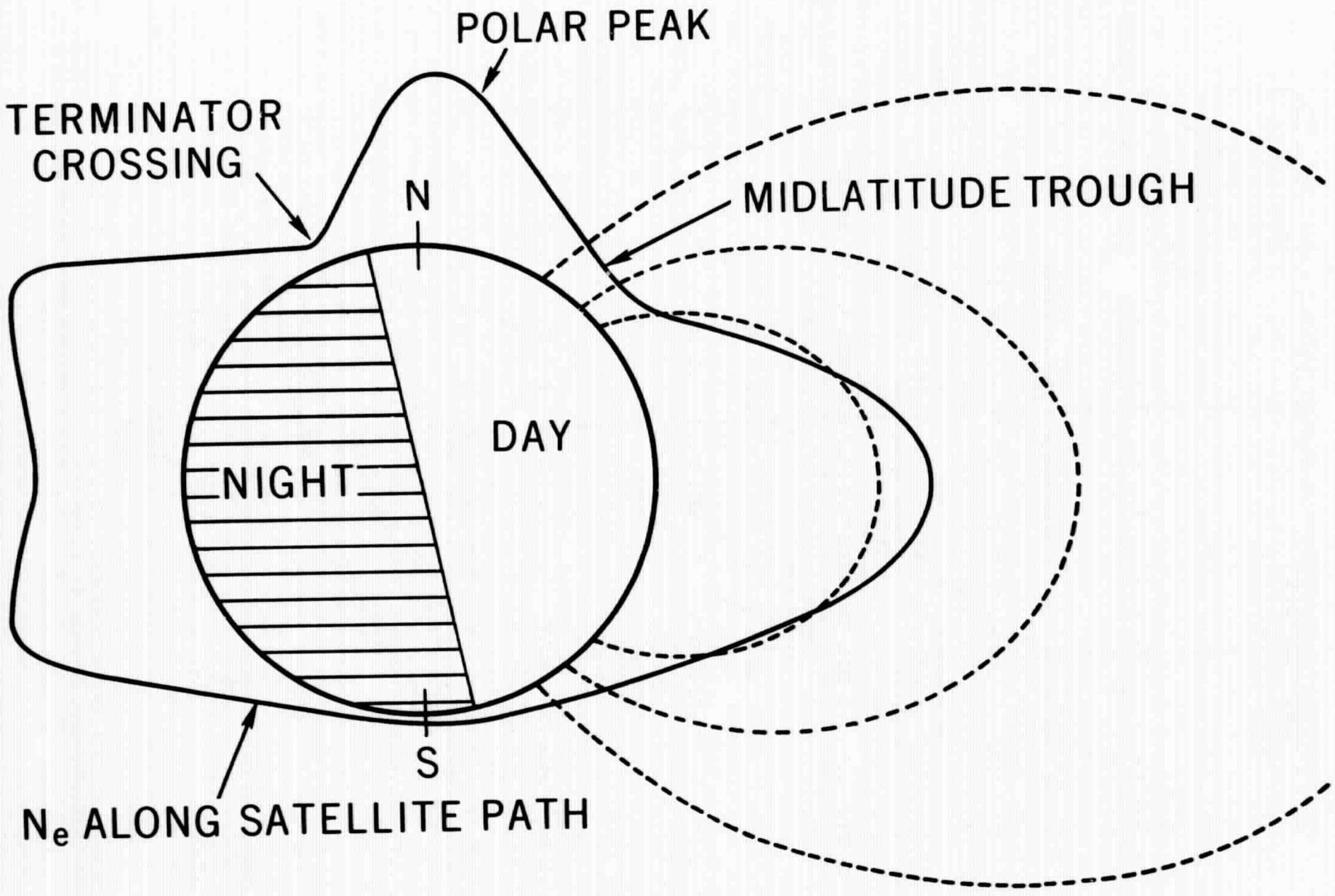

Figure 5–Sketch of the relationship between the terminator, the polar peak and the trough for a day in northern summer. The magnetic field is represented by dashed lines.

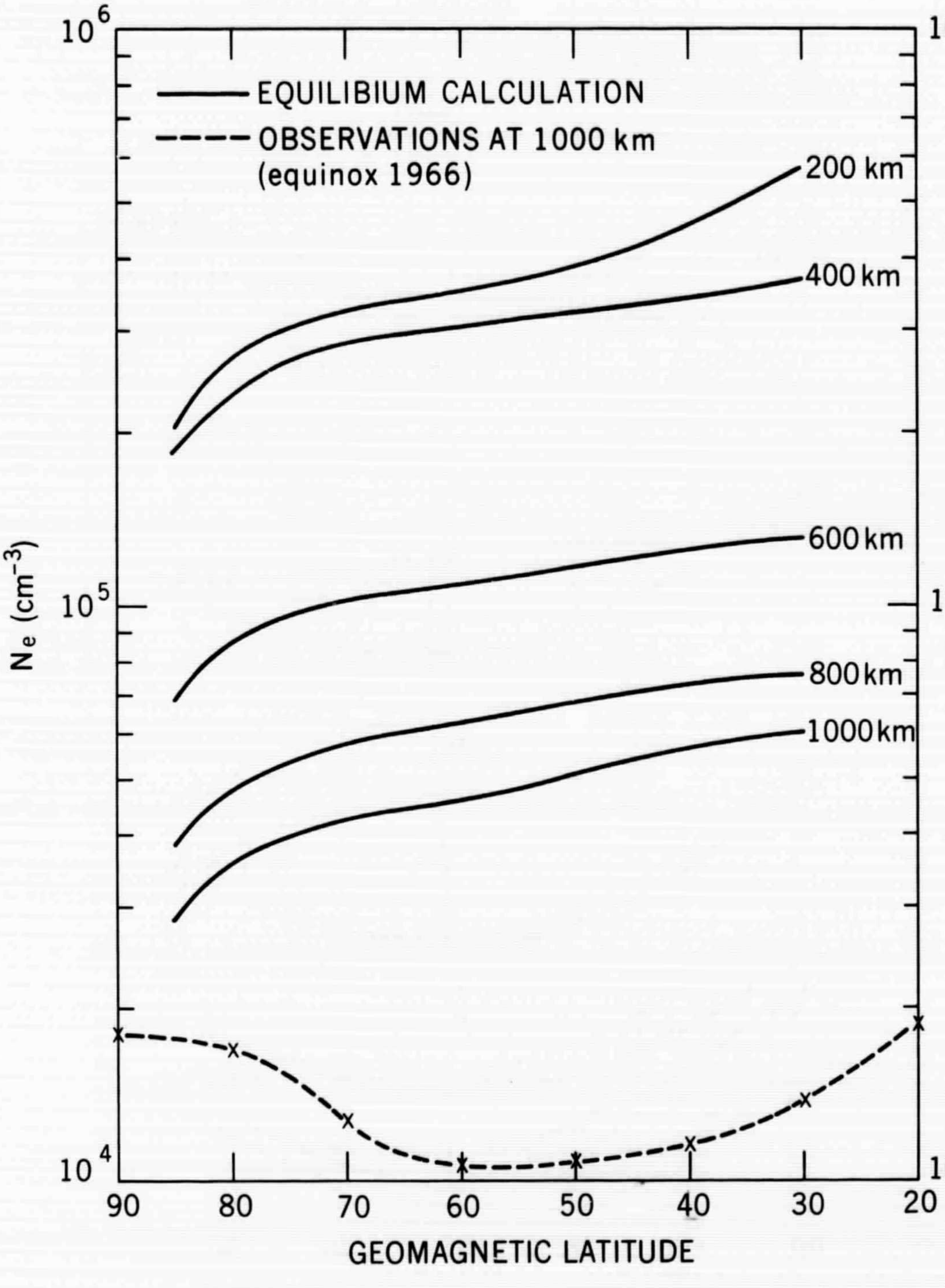

Figure 6–Calculations of the latitudinal variation of N_e at several altitudes for an ionosphere in equilibrium. There is no evidence of the midlatitude trough that is observed at 1000 km (crosses).

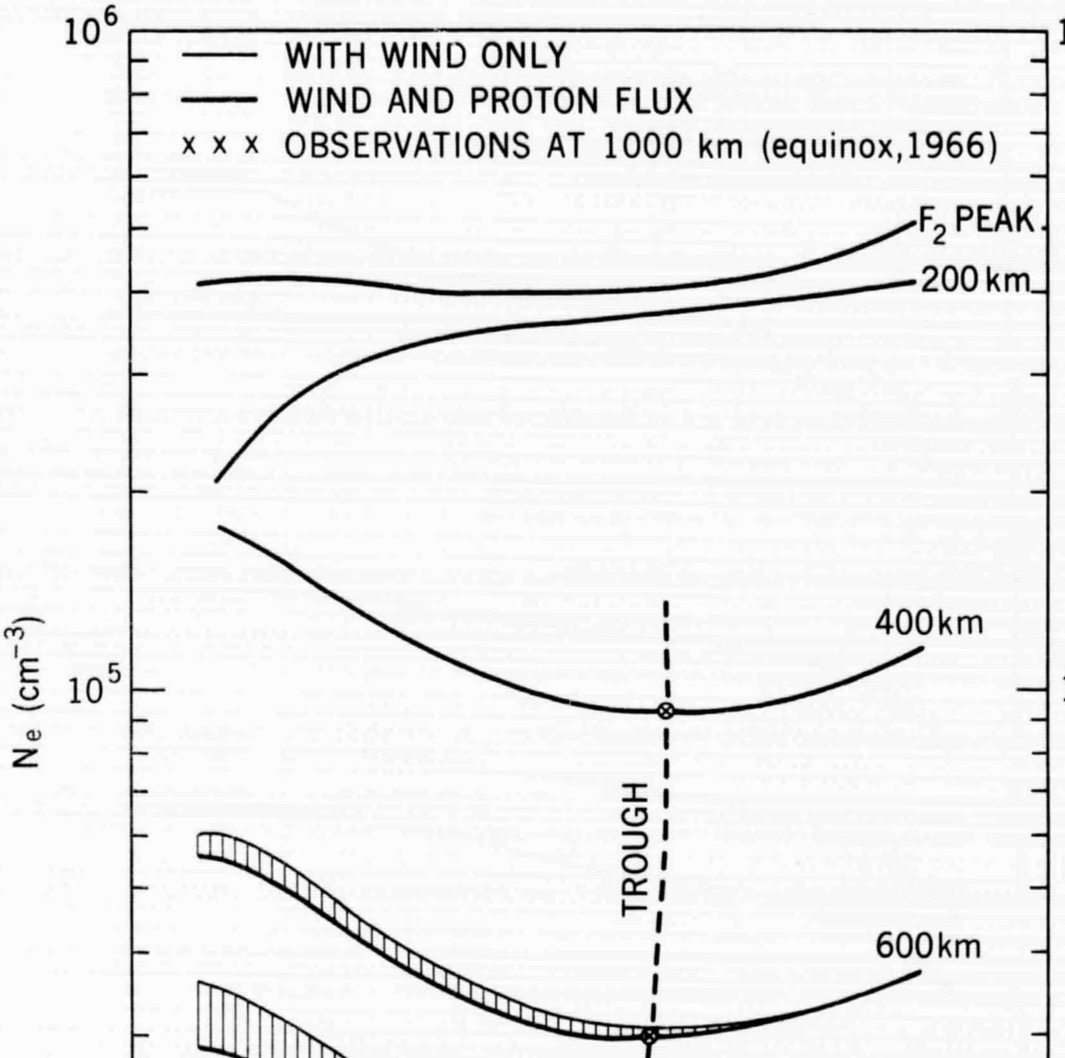

Figure 7-Calculation of the latitudinal variation of N_e when a poleward neutral wind is introduced (narrow solid line) and when a upward proton flux is added to the neutral wind (heavy line).